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DISSOLUTION STUDIES OF UO_2
IN SIMULATED LUNG FLUID²

by

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ABSTRACT

Dissolution patterns of UO_2 aerosols in simulated lung fluid were studied using UO_2 powder and aerosol samples obtained from two Canadian fuel fabrication plants which manufacture fuel elements for CANDU reactors.

Measurements were taken over fifty-nine days for aerosol samples and one hundred twenty-two days for powder samples. Dissolution rates were calculated by using the fractions of uranium remaining undissolved at various intervals of time.

The results of this study suggest that UO_2 powder used and aerosols generated in the two fuel fabrication plants are predominantly Class Y materials.

RÉSUMÉ

On a étudié la vitesse de dissolution des aérosols d' UO_2 dans du liquide pulmonaire simulé en utilisant des échantillons d' UO_2 en poudre et sous forme d'aérosols en provenance de deux usines de fabrication de combustibles canadiennes qui produisent des éléments combustibles pour les réacteurs CANDU.

Les mesures ont été faites pendant 59 jours dans le cas des aérosols et pendant 122 jours dans le cas des échantillons en poudre. On a calculé le taux de dissolution de chacun en mesurant la fraction d'uranium non dissoute à divers moments.

Les résultats de l'étude laissent entendre que l' UO_2 en poudre utilisé et l' UO_2 généré sous forme d'aérosols dans les deux usines de fabrication de combustibles étaient surtout des matières de classe Y.

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DISSOLUTION STUDIES OF UO_2
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I INTRODUCTION

The object of this study was to measure the in vitro dissolution rate of uranium particles in dust samples collected at various locations within two fuel fabrication plants which manufacture fuel elements for CANDU reactors. Natural uranium in the form of uranium dioxide, UO_2 , is used as fuel in these reactors.

The dissolution rate of UO_2 is a major factor in the determination of the clearance of deposited material from lung, especially from the lower respiratory tract (1,2), to extracellular fluids. The International Commission on Radiological Protection, ICRP, developed the Task Group Lung Model (3) which is used in computing the radiation dose from radionuclides deposited in the lung. The model uses transfer coefficients and clearance rates established by the ICRP. Based on dissolution characteristics, all radionuclides are divided into three classes, D, W and Y, corresponding to biological half lives of up to 10 days, up to 100 days and more than 100 days, respectively. Because of difficulties involved in obtaining biological data, especially on humans, several studies have been conducted to characterize the solubility of various uranium compounds and other radionuclides using simulated lung fluids (4-10). The ICRP made use of the results of some of these studies in approximating clearance half-times of radionuclides deposited in lung and assigned the values of transport rates from lung to other organs (3,6).

Assessment of internal contamination of occupationally exposed uranium workers in Canadian fuel fabrication plants is frequently performed by bioassay and in vivo counting methods. Although these data are often used in estimating the retention and distribution of deposited uranium compounds, it is difficult to reliably estimate the dissolution characteristics of the material (11). The present study was designed to measure dissolution rates in simulated lung

fluid of UO_2 samples obtained from fuel fabrication plants and to compare the results with values from the literature.

II MATERIALS AND METHODS

1. Samples

Uranium aerosol samples were collected by the plant personnel at various locations within the plants as determined by the staff health physicists at the following two fuel fabrication plants:

Westinghouse Canada Ltd.
Dorset Street East
Port Hope, Ontario, CANADA

Canadian General Electric
1025 Lansdowne Avenue
Toronto, Ontario, CANADA.

Both plants received natural uranium dioxide powder from Canada's only refinery, Eldorado Resources Limited, Port Hope, Ontario. The UO_2 powder was pressed into cylindrical slugs, passed through a furnace and sintered into pellets. Thus the UO_2 powder is subjected to only a thermal treatment and no chemical reprocessing is done at the plants during the manufacture of fuel rods.

Using 2.5 cm millipore membrane filters of 0.8 micron pore size, five aerosol samples were collected over a 2-week period and in addition two powder samples (preprocessed and sintered) from each plant were also obtained for the study. The details of sampling locations within each plant and a typical analysis of the powder sample received from the refinery are given in Table 1.

2. Simulated Lung Fluid

A comparison of ionic compositions of actual lung fluid (12) and simulated lung fluid (13) is presented in Table 2.

The simulated lung fluid was prepared according to Moss (13) by slowly adding the following ingredients, in order, to 990 mL of distilled water:

0.2033 g $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$
 6.0193 g NaCl
 0.2982 g KCl
 0.2680 g $\text{Na}_2\text{HPO}_4 \cdot 7\text{H}_2\text{O}$
 0.0710 g Na_2SO_4
 0.3676 g $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$
 0.9526 g $\text{NaH}_2\text{C}_2\text{O}_4 \cdot 3\text{H}_2\text{O}$
 2.6043 g NaHCO_3
 0.0970 g $\text{Na}_3\text{H}_5\text{C}_6\text{O}_7 \cdot 2\text{H}_2\text{O}$

The final volume was brought up to 1000 mL and the final pH of the solution was adjusted to 7.3 - 7.4 with the addition of small volumes of HCl as necessary. Fresh volumes of 1000 mL were made as required throughout the experimental period.

3. Dissolution Method

The UO_2 aerosol filter and powder samples were placed in 50 mL centrifuge conibottom positive seal plastic vials (Can. Lab. Catalogue No. C3978-50). The whole filter papers containing UO_2 dust were placed vertically in the vials. A fresh solution of 25 mL simulated lung fluid was added to each sample and the vials were sealed with plastic caps. The vials were then placed in a shaking water bath and agitated continuously to obtain maximum dissolution rates. The temperature of the water bath was maintained at $37^\circ\text{C} \pm 1^\circ$ throughout the experiment.

The vials were removed from the water bath at the end of a selected time interval and centrifuged to force undissolved residue into the conical end of the vial. After opening the cap, the supernatant solution from each vial was pipetted into 25 mL Erlenmeyer flasks and closed with a glass stopper. A fresh solution of 25 mL simulated lung fluid was added to each of the vials containing undissolved residue, sealed with caps and transferred to the shaker

water bath. All the steps were repeated at the end of each time interval determined previously.

The dissolution study of the aerosol filter samples was continued up to 59 days with 16 time intervals of sampling. The UO_2 powder samples were kept for 122 days with 17 time intervals of supernatant sampling.

4. Uranium Analysis

Uranium analysis of samples was done by two methods. All the supernatant samples taken at various intervals were analyzed for uranium, by laser fluorometric method on a Scintrex UA-3 uranium analyser (14). The UA-3 analyser has a minimum detection limit of 0.05 ppb and a measurement range of 2 to 20 ppb full scale. The measurement accuracy is within $\pm 15\%$ at 1 ppb level and above. Appropriate dilutions (up to 700 times) were used to analyse U in the samples within the measurement range of the UA-3 analyzer. The final residue containing the filter paper was dissolved by digestion with nitric, perchloric and hydrofluoric acids followed by appropriate dilution. The amount of uranium remaining undissolved in the final residue of the sample was analysed by neutron activation and delayed neutron counting method (15) at the laboratories of the Atomic Energy of Canada Limited (AECL) in Ottawa. The assay minimum detection limit is 0.1 μg U with a precision range of $\pm 10\%$ at 1 ppm U and $\pm 5\%$ at 10 ppm U as given in the manual (15).

5. Dissolution Rates

The dissolution half-times were described by the sum of exponentials of the form:

$$F = f_1 \exp(-0.693 t/T_1) + \dots + f_n \exp(-0.693 t/T_n)$$

where

F = the fraction of uranium remaining undissolved at any time interval t .

$f_1 - f_n$ = initial weight fractions of uranium components in the sample with dissolution half times of T_1 to T_n .

t = any time interval of corresponding undissolved uranium fraction F .

$T_1 - T_n$ = dissolution half-times of corresponding fraction of components in the sample.

In the actual model equations used in this study for computing the terms $0.693/T_1 \dots 0.069/T_n$ were replaced by $\lambda_1 \dots \lambda_n$.

The F values were calculated by subtracting the amount of uranium dissolved during any time interval from the amount of uranium present undissolved at the starting of that time interval and dividing the result by the total amount of uranium present in the sample at the start of the study. The F values were plotted against corresponding times ' t ' and by graphical analysis preliminary f_1 and T_1 values were obtained. The calculated values of f_1 , T_1 were used as initial values in a computer program developed to solve the exponential equations.

The computer program written in FORTRAN language and run on a HP-1000 system estimates up to four terms (eight parameters) by iterative process using modified Newton-Raphson Method (16). The best estimates are chosen based on the minimum value of the residual sum of squares of the iterative sets of values.

III RESULTS

Amounts of uranium dissolved and the fraction of total uranium remaining undissolved at various time intervals for fourteen samples are given in Tables 3 to 16 and are graphically presented in Figures 1 to 6. These graphs indicated the presence of a single curve, in most cases, in the beginning of the experimental period. Although UO_2 compound is classified as a Y compound, the samples in the present study indicated the presence of a small fraction that seemed to have a shorter dissolution half-time and, therefore, the dissolution data were fitted into a multiple exponential equation of the form

presented in the previous section, II-5. The results of the estimated fractions of uranium and their dissolution half-times are presented in Table 17.

Based on the values in Table 17 the UO_2 samples were then classified according to dissolution half-times in terms of ICRP Task Group Lung Model (3). These classifications presented in Table 18.

IV DISCUSSION

The results of the present study indicated a similar dissolution pattern of the UO_2 in dust samples collected within the two fuel fabrication plants. The two plants receive UO_2 powder from the same company and thus very little variation is expected in the composition of the powder. In general, the two plants also carry out similar fabrication processes in the manufacture of fuel pellets. The only major change that occurs to UO_2 powder is when it is passed through the sintering furnaces. The UO_2 is expected to be slightly more resistant to dissolution after it passes through the furnace. A similar pattern of dissolution can be expected at later processes, such as pellet grinding areas, compared to front-end operations.

The present results confirm the expected dissolution patterns of UO_2 aerosols in both the plants. The UO_2 dust generated in these two plants predominantly belonged to Class Y compounds and these results are in agreement with the classification reported in the literature (6,8,17,18).

The UO_2 in dust samples collected at the sintering furnace and pellet grinding areas in both the plants appeared to be slightly more resistant to dissolution compared to the dusts collected from pre-compaction and powder preparation areas. Similar differences in dissolution rates were apparent in pre-processed and sintered powder. The differences in the dissolution rates of UO_2 in aerosol samples collected within the press areas of the two plants can be explained only as the result of convection currents and air movement within the plant environment.

Less than one percent of UO_2 in dust samples collected at the furnace and grinding areas dissolved with a dissolution half-time of hours whereas up to 3% of UO_2 was dissolved with half-times of 3 to 8 days in the dusts collected at pre-compaction and powder preparation areas. Thus it is concluded that about 96 to 100% of the UO_2 generated in the environment of Canadian fuel fabrication plants can be classified as Class Y compound and about 0.2 to 3.3% as Class D according to ICRP classification.

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TABLE 1

SAMPLE DESCRIPTION

Location:

Westinghouse Canada Ltd.

Canadian General Electric

<u>No. of Samples</u>		<u>No. of Samples</u>	
Pre-compaction	1	Powder Preparation	
Press	1	Room	1
Furnace	1	Press Room	1
Grinder	1	Sintering Furnace	
Cut-off Saw	1	Area	1
Powder - Preprocessed	1	Pellet Grinding Room	2
Powder - Sintered	1	Powder - Preprocessed	1
		Powder - Sintered	1

Properties of Raw Material:

Compound:	Natural Uranium Dioxide (UO_2)
U (% sample basis):	87.15 to 87.41
O/U Ratio:	2.164
Bulk Density:	1.04
Moisture (% sample basis):	0.12
Green Density:	5.2 g/cc
Sintered Density:	10.61 g/cc

TABLE 2

COMPOSITIONS OF ACTUAL AND SIMULATED LUNG FLUIDS

<u>Ion</u>	<u>Actual</u>	<u>Simulated</u>
Calcium, Ca^{2+}	5.0 meq/L	5.0 meq/L
Magnesium, Mg^{2+}	2.0 "	2.0 "
Potassium, K^{+}	4.0 "	4.0 "
Sodium, Na^{+}	<u>145.0</u> "	<u>145.0</u> "
Total Cations	156.0 "	156.0 "
Bicarbonate, HCO_3^{-}	31.0 meq/L	31.0 meq/L
Chloride, Cl^{-}	114.0 "	114.0 "
Citrate, $\text{H}_5\text{C}_6\text{O}_7^{3-}$	-	1.0 "
Acetate, $\text{H}_3\text{C}_2\text{O}_2^{-}$	7.0 "	7.0 "
Phosphate, HPO_4^{2-}	2.0 "	2.0 "
Sulfate, SO_4^{2-}	1.0 "	1.0 "
Protein	<u>1.0</u> "	<u>.</u>
Total Anions	156.0 "	156.0 "
pH	7.3 - 7.4	7.3 - 7.4

TABLE 3

INCREMENTAL AMOUNTS OF URANIUM DISSOLVED
AND FRACTION OF TOTAL URANIUM REMAINING UNDISSOLVED
DURING DISSOLUTION OF PREPROCESSED POWDER SAMPLE FROM WCL

Time in Days	Amount of Uranium Dissolved	Fraction U Remaining Undissolved
	Ud ($\mu\text{g U}$)	F
.00	-	1.000
.09	75.00	.982
.19	3.45	.981
.27	.62	.981
.35	.73	.981
.44	.45	.981
1.00	1.68	.980
1.25	.46	.980
2.04	.82	.980
3.04	.52	.980
4.00	4.29	.980
5.00	.37	.979
7.00	1.08	.979
13.88	1.84	.978
28.00	2.07	.977
49.00	6.01	.976
70.00	3.54	.975
122.00	1.78	.975
Residue	4,040.00 μg	
Total Uranium in Sample	4,365 μg	

TABLE 4

INCREMENTAL AMOUNTS OF URANIUM DISSOLVED
AND FRACTION OF TOTAL URANIUM REMAINING UNDISSOLVED
DURING DISSOLUTION OF SINTERED POWDER SAMPLE FROM WCL

Time in Days	Amount of Uranium Dissolved	Fraction U Remaining Undissolved
	Ud (μ g U)	F
.00	-	1.000
.09	55.00	.989
.19	2.15	.988
.27	.10	.988
.35	.21	.988
.44	.04	.988
1.00	.03	.988
1.25	.04	.988
2.04	.04	.988
3.04	.05	.988
4.00	.08	.988
5.00	1.65	.987
7.00	1.59	.987
13.88	1.35	.987
28.00	1.03	.986
49.00	1.13	.986
70.00	1.28	.986
122.00	1.41	.986
Residue	4,780.00 μ g	
Total Uranium in Sample	4,847.2 μ g	

TABLE 5

INCREMENTAL AMOUNTS OF URANIUM DISSOLVED
AND FRACTION OF TOTAL URANIUM REMAINING UNDISSOLVED
DURING DISSOLUTION OF DUST COLLECTED AT WCL'S PRE-COMPACTION AREA

Time in Days	Amount of Uranium Dissolved	Fraction U Remaining Undissolved
	Ud ($\mu\text{g U}$)	F
.00	-	1.000
.08	.24	.989
.17	.03	.988
.25	.04	.986
.33	.01	.986
1.00	.01	.985
2.00	.01	.985
3.00	.01	.985
4.00	.01	.985
5.00	.01	.985
6.00	.01	.984
7.00	.01	.984
14.00	.01	.984
21.00	.01	.983
28.00	.01	.983
41.00	.01	.983
59.00	.01	.982
Residue	22 μg	
Total Uranium in Sample	22.39 μg	

TABLE 6

INCREMENTAL AMOUNTS OF URANIUM DISSOLVED
AND FRACTION OF TOTAL URANIUM REMAINING UNDISSOLVED
DURING DISSOLUTION OF DUST COLLECTED AT WCL'S PRESS AREA

Time in Days	Amount of Uranium Dissolved	Fraction U Remaining Undissolved
	Ud ($\mu\text{g U}$)	F
.00	-	1.000
.08	.44	.994
.17	.03	.994
.25	.01	.994
.33	.01	.994
1.00	.01	.994
2.00	.01	.994
3.00	.00	.994
4.00	.00	.994
5.00	.01	.993
6.00	.01	.993
7.00	.00	.993
14.00	.02	.993
21.00	.02	.993
28.00	.02	.993
41.00	.02	.992
59.00	.02	.992
Residue	78 μg	
Total Uranium in Sample	78.62 μg	

TABLE 7

INCREMENTAL AMOUNTS OF URANIUM DISSOLVED
AND FRACTION OF TOTAL URANIUM REMAINING UNDISSOLVED
DURING DISSOLUTION OF DUST COLLECTED AT WCL'S FURNACE AREA

Time in Days	Amount of Uranium Dissolved	Fraction U Remaining Undissolved
	Ud ($\mu\text{g U}$)	F
.00	-	1.000
.08	.39	.994
.17	.05	.993
.25	.02	.993
.33	.01	.993
1.00	.00	.993
2.00	.01	.993
3.00	.01	.993
4.00	.00	.993
5.00	.01	.993
6.00	.01	.992
7.00	.09	.991
14.00	.02	.991
21.00	.01	.991
28.00	.01	.990
41.00	.02	.990
59.00	.01	.990
Residue	66 μg	
Total Uranium in Sample	66.67 μg	

TABLE 8

INCREMENTAL AMOUNTS OF URANIUM DISSOLVED
AND FRACTION OF TOTAL URANIUM REMAINING UNDISSOLVED
DURING DISSOLUTION OF DUST COLLECTED AT WCL'S GRINDER AREA

Time in Days	Amount of Uranium Dissolved	Fraction U Remaining Undissolved
	Ud ($\mu\text{g U}$)	F
.00	-	1.000
.08	.19	.996
.17	.03	.996
.25	.01	.995
.33	.01	.995
1.00	.00	.995
2.00	.00	.995
3.00	.00	.995
4.00	.00	.995
5.00	.00	.995
6.00	.01	.995
7.00	.01	.995
14.00	.01	.994
21.00	.01	.994
28.00	.01	.994
41.00	.01	.994
59.00	.01	.993
Residue	49 μg	
Total Uranium in Sample	48.32 μg	

TABLE 9

INCREMENTAL AMOUNTS OF URANIUM DISSOLVED
AND FRACTION OF TOTAL URANIUM REMAINING UNDISSOLVED
DURING DISSOLUTION OF DUST COLLECTED AT WCL'S CUT-OFF SAW AREA

Time in Days	Amount of Uranium Dissolved	Fraction U Remaining Undissolved
	Ud ($\mu\text{g U}$)	F
.00	-	1.000
.08	.20	.998
.17	.03	.998
.25	.02	.998
.33	.00	.998
1.00	.01	.998
2.00	.01	.998
3.00	.00	.998
4.00	.00	.998
5.00	.01	.998
6.00	.01	.998
7.00	.01	.998
14.00	.01	.998
21.00	.02	.997
28.00	.02	.997
41.00	.03	.997
59.00	.02	.996
Residue	124 μg	
Total Uranium in Sample	124.39 μg	

TABLE 10

INCREMENTAL AMOUNTS OF URANIUM DISSOLVED
AND FRACTION OF TOTAL URANIUM REMAINING UNDISSOLVED
DURING DISSOLUTION OF PREPROCESSED POWDER SAMPLE FROM CGE

Time in Days	Amount of Uranium Dissolved	Fraction U Remaining Undissolved
	Ud ($\mu\text{g U}$)	F
.00	-	1.000
.09	98.78	.979
.19	1.07	.979
.27	.12	.979
.35	.05	.979
.44	.05	.979
1.00	.11	.978
1.25	.05	.978
2.04	.06	.978
3.04	.05	.978
4.00	.03	.978
5.00	.02	.978
7.00	.08	.978
13.88	.19	.978
28.00	.33	.978
49.00	.29	.978
70.00	.29	.978
122.00	.45	.978
Residue	4,575 μg	
Total Uranium in Sample	4,677.04 μg	

TABLE 11

INCREMENTAL AMOUNTS OF URANIUM DISSOLVED
AND FRACTION OF TOTAL URANIUM REMAINING UNDISSOLVED
DURING DISSOLUTION OF SINTERED POWDER SAMPLE FROM CGE

Time in Days	Amount of Uranium Dissolved	Fraction U Remaining Undissolved
	Ud (ug U)	F
.00	-	1.000
.09	32.50	.993
.19	2.09	.992
.27	.26	.992
.35	.24	.992
.44	.19	.992
1.00	.53	.992
1.25	.16	.992
2.04	.19	.992
3.04	.12	.992
4.00	.08	.992
5.00	.11	.992
7.00	.19	.992
13.88	.73	.991
28.00	1.60	.991
49.00	2.50	.990
70.00	.87	.990
122.00	.75	.990
Residue	4,400.00 ug	
Total Uranium in Sample	4,443.14 ug	

TABLE 12

INCREMENTAL AMOUNTS OF URANIUM DISSOLVED
AND FRACTION OF TOTAL URANIUM REMAINING UNDISSOLVED
DURING DISSOLUTION OF DUST COLLECTED AT CGE'S POWDER PREPARATION ROOM

Time in Days	Amount of Uranium Dissolved	Fraction U Remaining Undissolved
	Ud ($\mu\text{g U}$)	F
.00	-	1.000
.08	12.38	.971
.17	1.08	.968
.25	.22	.968
.33	.10	.968
1.00	.17	.967
2.00	.09	.967
3.00	.05	.967
4.00	.04	.967
5.00	.02	.967
6.00	.06	.967
7.00	.47	.965
14.00	.31	.964
21.00	.23	.964
28.00	.23	.963
41.00	.35	.962
59.00	.27	.962
Residue	411 μg	
Total Uranium in Sample	427.087 μg	

TABLE 13

INCREMENTAL AMOUNTS OF URANIUM DISSOLVED
 AND FRACTION OF TOTAL URANIUM REMAINING UNDISSOLVED
 DURING DISSOLUTION OF DUST COLLECTED AT CGE'S PRESS (COMPACTION) ROOM

Time in Days	Amount of Uranium Dissolved	Fraction U Remaining Undissolved
	Ud ($\mu\text{g U}$)	F
.00	-	1.000
.08	14.37	.977
.17	1.17	.975
.25	.38	.974
.33	.17	.974
1.00	.31	.974
2.00	.13	.973
3.00	.05	.973
4.00	.73	.972
5.00	.03	.972
6.00	.02	.972
7.00	.43	.971
14.00	1.06	.970
21.00	.64	.969
28.00	.48	.968
41.00	.70	.967
59.00	.39	.966
Residue	605 μg	
Total Uranium in Sample	628.08 μg	

TABLE 14

INCREMENTAL AMOUNTS OF URANIUM DISSOLVED
AND FRACTION OF TOTAL URANIUM REMAINING UNDISSOLVED
DURING DISSOLUTION OF DUST COLLECTED AT CGE'S SINTERING FURNACE AREA

Time in Days	Amount of Uranium Dissolved	Fraction U Remaining Undissolved
	Ud ($\mu\text{g U}$)	F
.00	-	1.000
.08	.83	.998
.17	.07	.998
.25	.03	.998
.33	.01	.998
1.00	.03	.998
2.00	.02	.998
3.00	.01	.998
4.00	.01	.998
5.00	.01	.998
6.00	.00	.998
7.00	.00	.998
14.00	.06	.998
21.00	.03	.998
28.00	.03	.998
41.00	.05	.997
59.00	.03	.997
Residue	498 μg	
Total Uranium in Sample	499.25 μg	

TABLE 15

INCREMENTAL AMOUNTS OF URANIUM DISSOLVED
 AND FRACTION OF TOTAL URANIUM REMAINING UNDISSOLVED
 DURING DISSOLUTION OF DUST COLLECTED AT CGE'S PELLET GRINDING ROOM I

Time in Days	Amount of Uranium Dissolved	Fraction U Remaining Undissolved
	Ud ($\mu\text{g U}$)	F
.00	-	1.000
.08	1.20	.997
.17	.12	.996
.25	.06	.996
.33	.04	.996
1.00	.03	.996
2.00	.01	.996
3.00	.00	.996
4.00	.00	.996
5.00	.00	.996
6.00	.00	.996
7.00	.01	.996
14.00	.01	.996
21.00	.05	.996
28.00	.04	.995
41.00	.08	.995
59.00	.06	.995
Residue	369 μg	
Total Uranium in Sample	370.766 μg	

TABLE 16

INCREMENTAL AMOUNTS OF URANIUM DISSOLVED
AND FRACTION OF TOTAL URANIUM REMAINING UNDISSOLVED
DURING DISSOLUTION OF DUST COLLECTED AT CGE'S PELLET GRINDING ROOM II

Time in Days	Amount of Uranium Dissolved	Fraction U Remaining Undissolved
	Ud ($\mu\text{g U}$)	F
.00	-	1.000
.08	.991	.998
.17	.125	.997
.25	.095	.997
.33	.070	.997
1.00	.050	.997
2.00	.010	.997
3.00	.010	.997
4.00	.000	.997
5.00	.010	.997
6.00	.000	.997
7.00	.010	.997
14.00	.060	.997
21.00	.050	.997
28.00	.050	.997
41.00	.080	.996
59.00	.050	.996
Residue	456 μg	
Total Uranium in Sample	457.66 μg	

TABLE 17

DISSOLUTION FRACTIONS (f) AND HALF-TIMES ($t_{1/2}$)
 OF UO_2 IN SAMPLES COLLECTED WITHIN
 TWO FUEL FABRICATION PLANTS

SAMPLE	f_1	$t_{1/2}^{(1)}$ in days	f_2	$t_{1/2}^{(2)}$ in days	f_3	$t_{1/2}^{(3)}$ in days
<u>WCL</u>						
Aerosols:						
Pre-compaction	0.013	0.06	0.003	8	0.984	7804
Press	0.007	0.03	0.993	41250		
Furnace	0.007	0.03	0.993	9625		
Grinder	0.004	0.02	0.996	infinity		
Cut-off	1.000	infinity				
Powder:						
Preprocessed	0.020	0.03	0.980	12030		
Sintered	0.010	0.005	0.990	infinity		
<u>CGE</u>						
Aerosols:						
Powder Prep.	0.032	0.02	0.001	3.7	0.967	6016
Press	0.026	0.03	0.003	2.9	0.971	6417
Furnace	0.002	0.005	0.998	infinity		
Grinder	0.004	0.04	0.996	infinity		
Grinder	0.004	0.12	0.996	infinity		
Powder:						
Preprocessed	0.020	0.005	0.980	32080		
Sintered	0.007	0.005	0.993	24060		

TABLE 18

DISSOLUTION-RATE CLASSIFICATION OF
 UO_2 SAMPLES BASED ON THE ICRP SYSTEM

SAMPLE	CLASSIFICATION
<u>WCL</u>	
Aerosols:	
Pre-compaction	1.6% D, 98.4% Y
Press	0.7% D, 99.3% Y
Furnace	0.7% D, 99.3% Y
Grinder	0.4% D, 99.6% Y
Cut-off	- 100% Y
Powders:	
Preprocessed	2% D, 98% Y
Sintered	1% D, 99% Y
<u>CGE</u>	
Aerosols:	
Powder Preparation	3.3% D, 96.7% Y
Press	2.9% D, 97.1% Y
Furnace	0.2% D, 99.8% Y
Grinder	0.4% D, 99.6% Y
Grinder	0.4% D, 99.6% Y
Powders:	
Preprocessed	2% D, 98% Y
Sintered	0.7% D, 99.3% Y

FIGURE 1
IN VITRO DISSOLUTION OF UO₂ POWDER
SAMPLES

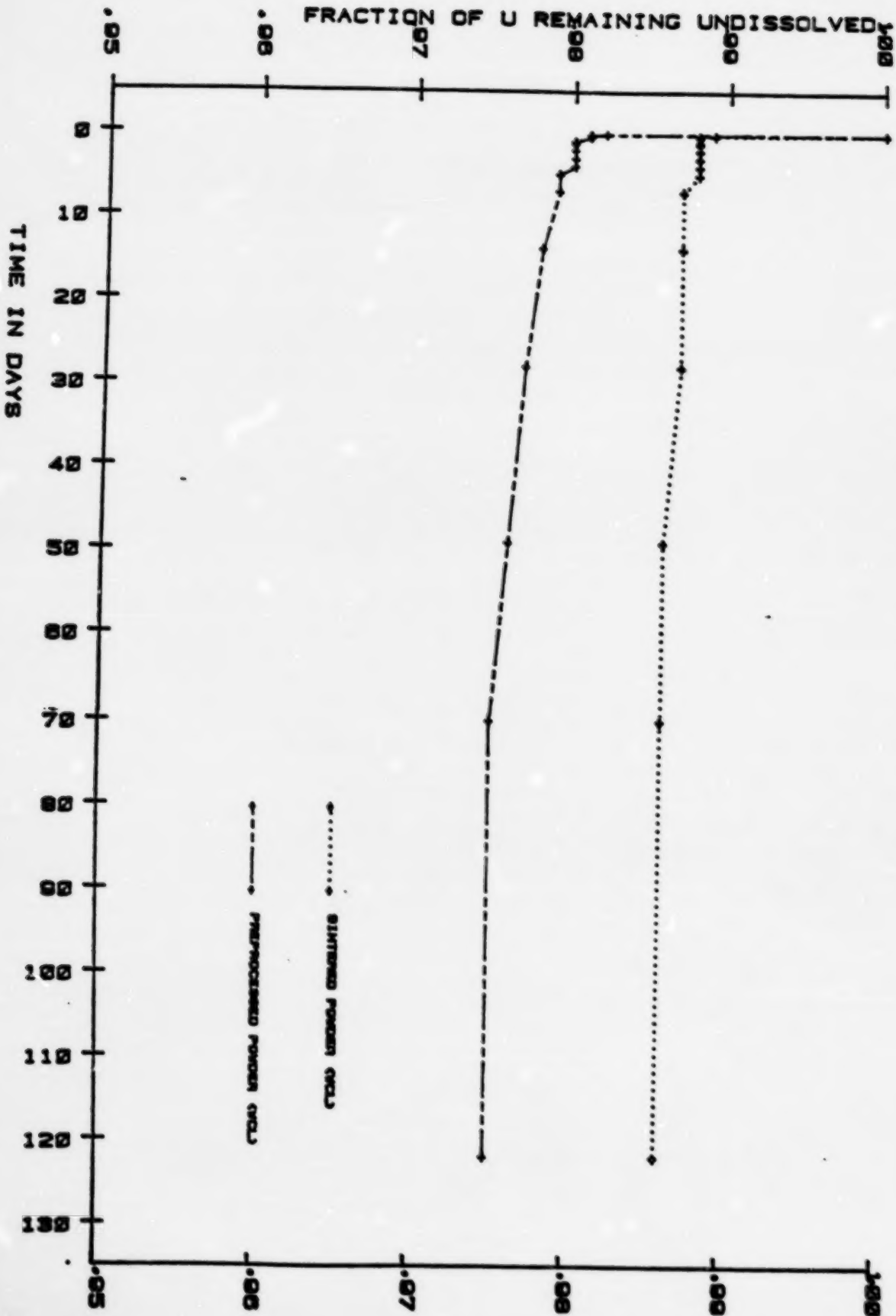


FIGURE 2

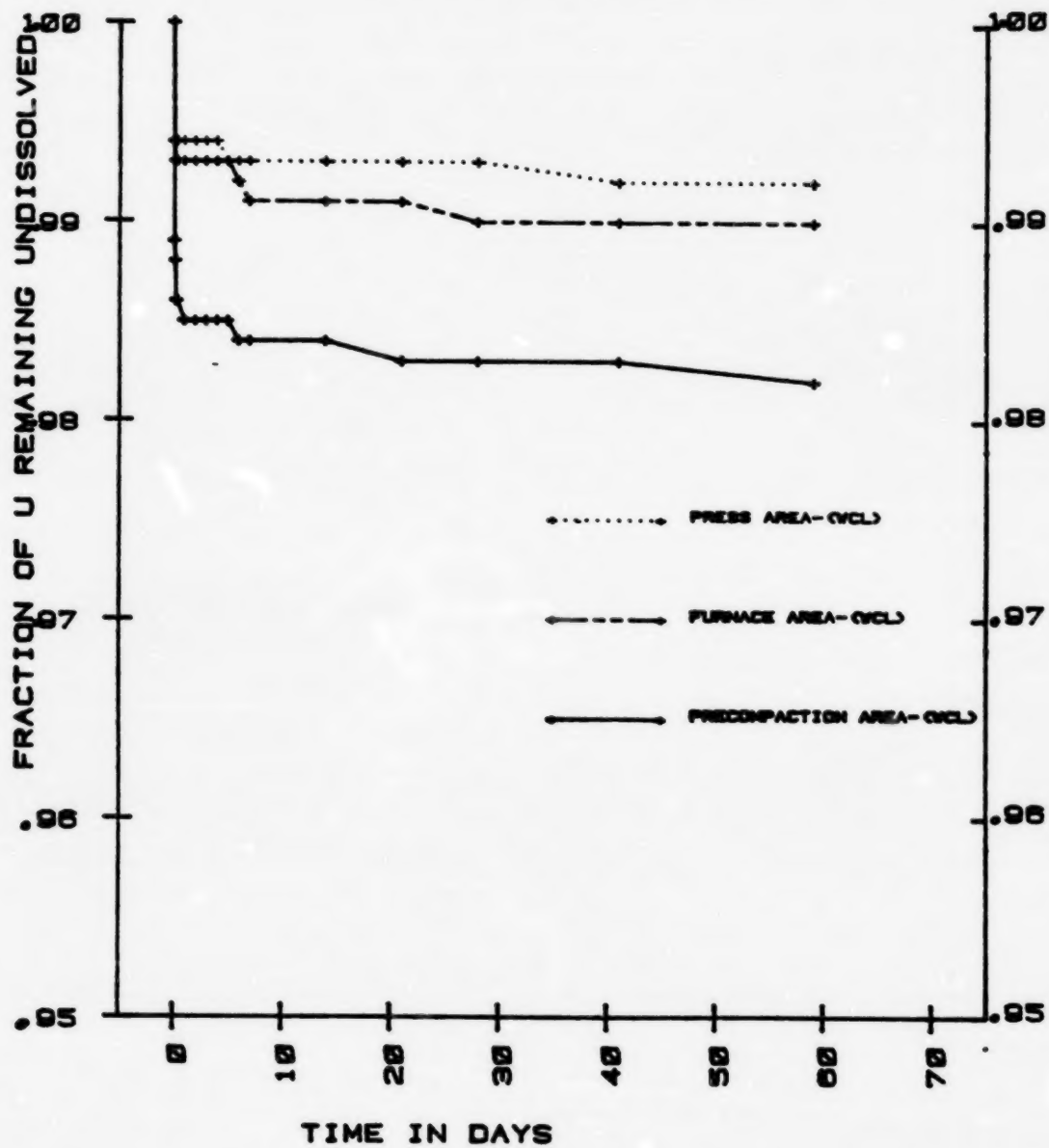
IN VITRO DISSOLUTION OF UO_2 IN AEROSOLS

FIGURE 3

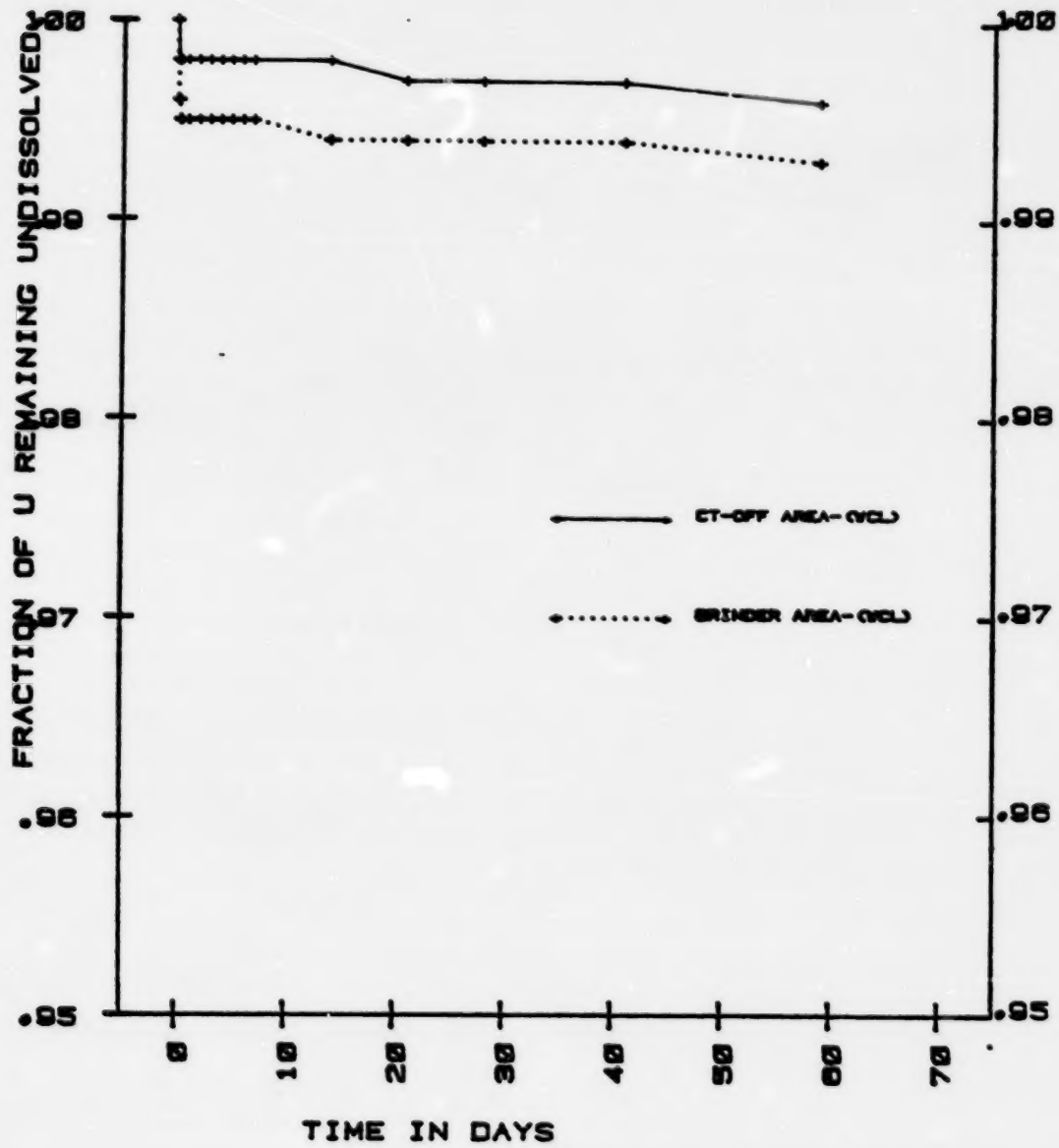
IN VITRO DISSOLUTION OF UO₂ AEROSOLS

FIGURE 4

IN VITRO DISSOLUTION OF UO₂ POWDER SAMPLES

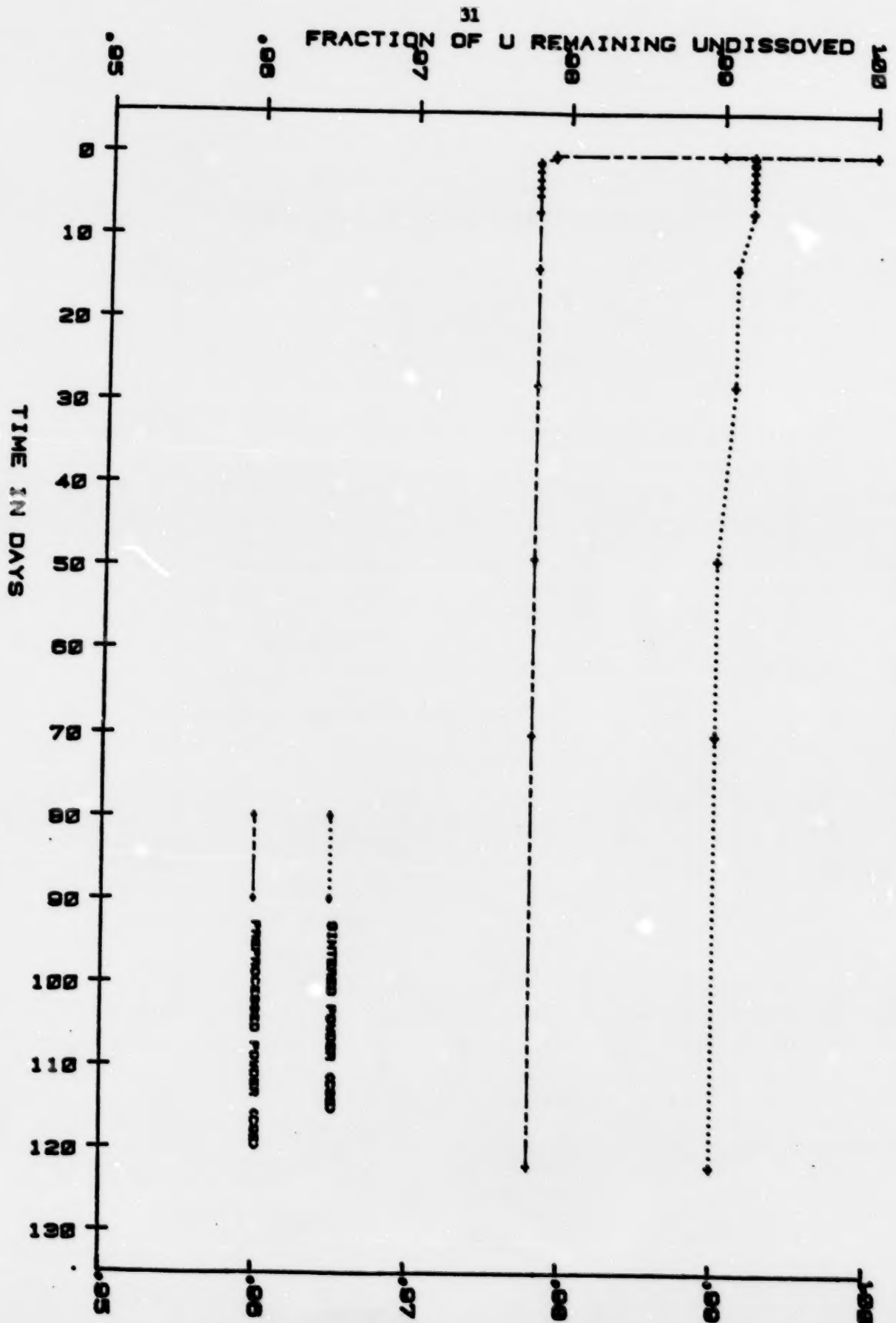


FIGURE 5

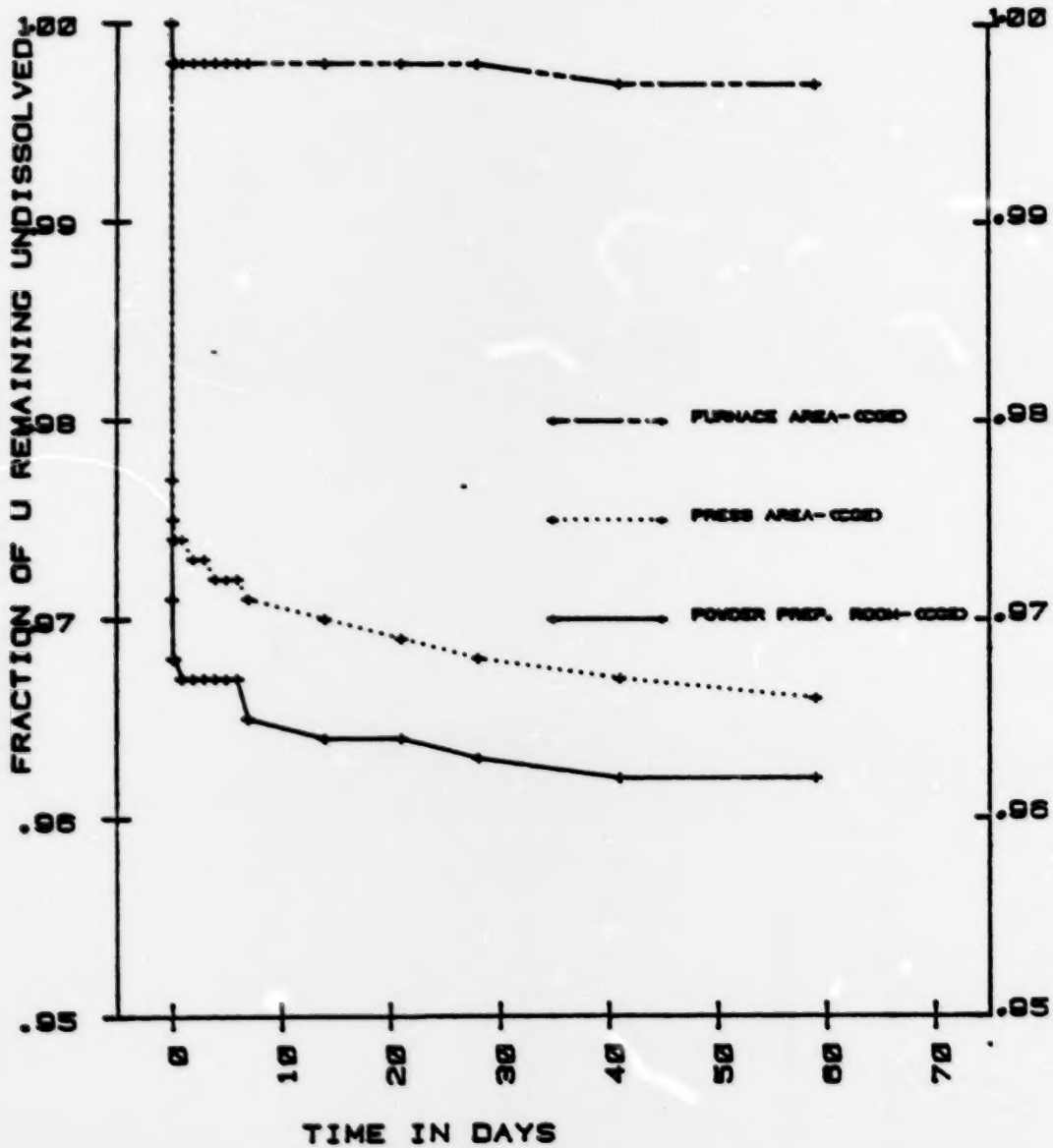
IN VITRO DISSOLUTION OF UO_2 AEROSOLS

FIGURE 6

IN VITRO DISSOLUTION OF UO_2 AEROSOLS